1993

Carbon dioxide evolution of high moisture corn treated with iprodione

Slaven Aljinovic
Iowa State University

Carbon dioxide evolution of high moisture
corn treated with iprodione

by

Slaven Aljinovic

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
requirements for the Degree of
MASTER OF SCIENCE

Interdepartmental Program: General Graduate Studies
Major: General Graduate Studies (Biological Sciences)

Signatures have been redacted for privacy

Iowa State University
Ames, Iowa

1993

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GENERAL INTRODUCTION

Corn (*Zea mays*) is one of world's most important agricultural crops. With 18% of the total area planted to cereals and 38% of the total cereals produced worldwide, corn ranks 3rd in importance, only after wheat and rice (FAO, 1992). As with other agricultural crops, losses between field and consumption can be great. Losses for corn can range up to 46%, a major part due to inadequate storage techniques and facilities, prestorage and storage handling (FAO, 1985). Corn is also one of the major crops in Croatia, and storage losses constitute a major problem. Therefore, I decided to complete a research study on the subject of corn storage losses, and ways to reduce them.

While preparing for the experimental trials and going through the existing literature, I became aware of the problems associated with the heavy dependance of modern agriculture on agricultural chemicals. The corn production cycle is one of the best examples. Therefore, I have concentrated part of my studies on some problems connected with the use of agricultural chemicals, their environmental impacts and possible alternatives to their use in the future.

Corn Preservation

A major approach towards solving the problem of storage losses has been development and use of preservative chemicals. As a result of longterm research, Rhone-Poulenc Company has developed a preservative chemical, marketed as Rovral fungicide, with iprodione as its active component.

The principal objective of my study was to determine the preservative effect of Rovral on deterioration rates of stored high-moisture corn. However, other factors may play an important part in corn storage life. Therefore parts of my studies were focused on the fields of agriculture that explain the influences grain harvesting as well as prestorage and storage conditions have on corn deterioration rates. Since the experimental setup was a controlled environment, through a course on this topic, I learned more about the principles and methods of maintaining a controlled environment. This greatly helped me in conducting the experiment. Statistics is the tool we use to interpret our final experimental results, therefore in my studies I included a course in the field of statistics for researchers in agriculture.

Studies on corn storage deterioration have revealed significant differences in corn hybrids due to genetic differences among them. I believe that fields of biotechnology, such as plant tissue culture, hold many surprises still to be discovered. Among them are the genetic mechanisms involved in storage deterioration resistance of certain corn hybrids. Research in the field of plant tissue culture could enable us to produce, or transfer from wild relatives, selected genetic traits that would enhance the deterioration resistance of corn.

Agricultural Environmental Protection

With 640 million kg of pesticide applied in the U.S. during 1987 (Ware, 1989), pesticides are important sources of environmental pollution. Keeping in mind the economic aspects of production, the greatest challenge we are faced with is to minimize the adverse effects of agricultural chemicals on environment and mankind. Other fields of science may offer us answers on how to reduce the use of chemicals in modern agriculture and provide us with ways to solve environmental problems we are faced with.

Groundwater Pollution

One of the main environmental problems associated with modern corn production is groundwater pollution by agricultural chemicals. Once contaminated, groundwater has longlasting adverse effects on the environment. Some research show that 6000 years are needed for complete recycling of the groundwater aquifer (Simpkins, 1993). One of the key links in this system is the watershed. Proper watershed management can minimize the chances of groundwater contamination. Placement of buffer strips in riparian areas is one of the most effective ways to control movement of pesticides in the environment. Understanding the mode of pesticide action is important in predicting their fate. This also enables us to develop more effective and environmentally safer pesticides in the future.

Biocontrol

An important approach to reducing the use of agricultural chemicals is the biocontrol of pests. Use of various methods of biocontrol, incorporated in an integrated pest management (IPM) system could greatly reduce environmental problems of pesticide residues and groundwater pollution.

Crop Diversity and Alternative Land Management

The last method to decrease the use of agricultural chemicals, within an IPM system, is crop diversification and alternative land management. Knowing the fact that 61.1% of cultivated land in Iowa is planted in two crops, corn and soybeans (Anonymous, 1991) further stresses the importance of agricultural diversification. The development of new pest resistant cash crops could provide a alternative to corn and the intensive use of pesticides. Land use, such as highly profitable game farming, could also provide an alternative to corn farming, further reducing the use of pesticides.

Explanation of Thesis Format

This thesis consists of one paper written in the format required for publication by the Journal of Food Protection. Because of the publication guidelines, tables and figures have been placed at the end of the paper. A general conclusion follows the paper. References cited in the general introduction follow the general conclusion.

The dissertation includes appendices A, B, C, and D. Appendix A gives raw data of the CO_2 evolution trials for the corn samples. Appendix B gives the corn sample weights. Appendix C gives the final moisture contents, and appendix D gives the equations for CO_2 production of corn samples treated with different fungicide treatments and different shelling methods. Appendices will not be included in the manuscript submitted for publication to the Journal of Food Protection.

CARBON DIOXIDE EVOLUTION OF HIGH-MOISTURE SHELLED CORN TREATED WITH IPRODIONE

Slaven Aljinovic, Carl J. Bern, Manjit K.Misra

ABSTRACT

Carbon dioxide evolution was used to determine the storage life of 22.7% moisture shelled corn. Four iprodione fungicide treatments plus an untreated control were tested. The fungicide was tested on corn having three levels of mechanical kernel damage: 7.1% (hand shelled), 25.3% (combine harvested), and 16.2% (a blend of the other two damage levels). All iprodione treatments significantly increased storage life compared to the untreated control. Fungicide activator did not significantly extendd the storage time to 0.5% dry matter loss (DML) when added to the 15 or 20 ppm Corn samples with higher levels of kernel damage had lower times to reach the 0.5% DML level. For combine shelled corn, fungicide treatments with activator increased storage life 26% for the 15 ppm treatment and 57% for the 20 ppm treatment.

INTRODUCTION

Harvesting corn at higher moisture content reduces field pest attacks, avoids bad weather consequences, and minimizes field losses. On the other hand, high moisture corn deteriorates rapidly in storage and can suffer a reduction in market value.

Carbon dioxide production has been used as an index of corn deterioration by Saul and Lind (1958), Saul and Steele (1966), Friday et al. (1989), Al-Yahya (1991), Wilcke et al. (1992) and others. They modeled respiration of a corn mass by the equation for oxidation of glucose:

$$C_6H_{12}O_6 + 6O_2 \text{ -----> } 6CO_2 + 6H_2O + 2835 \text{ kJ}$$

According to this equation, a 1% loss in grain dry matter (glucose) is accompanied by the evolution of 14.7 g CO_2/kg of CO_2. According to Saul and Steele (1966), corn can lose up to 0.5% of its dry matter or 7.35 g CO_2/kg dry matter through deterioration before grain quality is reduced by one commercial grade because of damaged kernels. Therefore, it is necessary to understand deterioration of shelled corn and ways to control it, such as use of mold inhibitors and design of drying and storage systems to minimize quality loss. The main factors influencing grain deterioration during storage are moisture content (Tuite et al. 1985), temperature (Thompson 1972), mechanical damage (Friday et al 1989, Stroshine and Yang 1990), conditions of previous storage (Fernandez et al. 1985), and hybrid resistance (Cantone et al. 1983, Moreno-Martinez and Christensen 1971, Friday et al. 1989, Al-Yahya et al. 1993).

Preservatives

Grain preservatives appear to have a potential to reduce deterioration rates over a wide range of moisture contents and temperatures. Potassium sorbate and various organic acids such as acetic, propionic, isobutyric, sorbic and formic acids or their mixtures have been used on high moisture corn to prevent mold infestation and growth (Sauer and Burroughs 1974, Ghate et al. 1980, Yasin and Hanna 1991). These compounds are effective, but they often impart an acrid odor to the treated corn and have other disadvantages. Studies by White et al. (1988), Al-Yahya (1991), and Al-Yahya et al. (1993) show that treating grain with commercial fungicides can reduce the grain deterioration rate.

Iprodione

Rhone-Poulenc Company markets Rovral fungicide, which contains iprodione as it active ingredient for use as a mold inhibitor. Rovral has been used on various crops such as lettuce, grapes, almonds and stone fruits (Rhone-Poulenc Ag Company, 1990). In laboratory studies, the active ingredient, iprodione, was not carcinogenic, teratogenic or mutagenic. Laboratory studies have also shown that iprodione has low mobility, no significant loss by volatilization, no tendency to bioacumulate in fish tissue, and no residues where found at harvest in field-grown crops a season following the treatment year (Rhone-Poulenc Ag Company, 1990). The half-life of the parent compound ranges from 7 to 40 days, depending on the soil type and climatic conditions.

Studies described in Al-Yahya (1991), Wilcke et al. (1992) and Al-Yahya et al. (1993) showed that iprodione treated corn samples had lower deterioration rates than untreated samples. The Al-Yahya study looked at hand-shelled corn, treated at the 20 ppm level. The present study was undertaken to determine effects of other factors including iprodione level, harvest damage, and fungicide carrier. Wilcke et al. (1992) studied the effects of these factors, but used smaller (200 g) corn samples in an automated system employing an infrared spectrometer for CO_2 detection.

OBJECTIVES

The objectives of this study were to : 1) Determine the preservative effects of 15 and 20 ppm iprodione fungicide on high moisture corn using the criterion of CO_2 evolution as an indicator of corn deterioration. 2) Determine effects of the fungicide carrier and corn damage level on the effectiveness of iprodione as a mold inhibitor.

MATERIALS AND METHODS

During 1992, evaluation of corn storage deterioration using CO_2 absorption method was carried out in the Grain Deterioration Laboratory in Davidson Hall at Iowa State University, Ames, Iowa.

Hybrid Selection

Pioneer 3475 hybrid was chosen for this study. It is a full season, high-yield variety recommended for use in Iowa and Minnesota, where collaborative testing is underway. The corn, Pioneer 3475, was harvested at the Iowa State University Agronomy Agricultural Engineering Center, 15 km west of Ames, Iowa, in September 1991. The corn moisture level at harvest time was 22 to 24%. Half of the corn was hand-harvested and hand-shelled and half was harvested and shelled with a combine. Corn was held at 4°C for four days and then was stored at -10°C until the start of research trials. This procedure was recommended by Fernandez et al. (1985) for corn that is used in corn storage life tests. Corn was removed from the freezer and held in a 10°C refrigerator 16 h prior to the start of each test. It was then held at room temperature (20°C) for 8 h while being thawed, cleaned over a 4.76-mm (12/64-in) round-hole screen, and treated with fungicide.

Sample Treatment

In this study, samples having three levels of mechanical kernel damage and five mold inhibitor treatments were prepared. Since two replicate tests were conducted for each treatment, a total of 30 samples were treated. Chowdhury's method (Chowdhury and Buchele, 1976) of determining kernel damage was used to determine mechanical damage level. Hand-shelled corn averaged 7.1% mechanical damage and combine-shelled corn 25.3%. To get a sample with the third level of kernel damage, a mixture of half hand-shelled and half-combine shelled corn (half and half) was prepared and the level of kernel damage was assumed to be 16.2%. The mold inhibitor used in our study was iprodione fungicide. Two of the treatments included a nonionic surfactant, Activator 90 (marketed by Rhone-Poulenc Ag. Company), added at the rate of 0.25% volume surfactant per volume iprodione solution. Treatments included:

* control (no fungicide, but a equivalent amount of water).
* 15 ppm iprodione (wet basis weight of iprodione / wet weight of corn).
* 15 ppm + surfactant.
* 20 ppm iprodione.

* 20 ppm iprodione + surfactant.

Fungicide was applied to the corn using laboratory pipettes. Samples where mixed in a small laboratory-sized Gustafson seed treater for 10 minutes to get uniform coating of all kernels. After treatment, samples where placed in plexiglass storage tubes within the CO_2 absorption system.

Storage Apparatus and Procedures

Carbon dioxide production during storage of corn with five different mold inhibitor treatments was measured by an absorption technique similar to that used by Al-Yahya (1991) with minor changes in the CO_2 removal section. The system operated at 20 ± 0.5°C and consisted of sections having the following functions: 1) CO_2 removal and air humidification 2) sample storage and aeration 3) water absorption and 4) CO_2 absorption. Each experiment included six separate CO_2 absorption tubes that allowed two replicates of three different corn kernel damage levels.

The first section, used for CO_2 removal and air humidification, consisted of a Fisher-Milligan gas washing bottle followed by a Drechsel gas washing bottle. CO_2 was removed from the entering air by bubbling it through a potassium hydroxide solution (30% KOH by weight). Next, the air was bubbled through water and then through a saturated K_2SO_4 solution. This gave the air the appropriate relative humidity needed to maintain the corn at a moisture content of about 22%. However, control of moisture at the 22% level proved to be difficult. The moisture content of the corn samples ranged from 20 to 24.3%, with the average moisture for all treatments at 22.7% (Appendix C).

The storage section consisted of 90-cm long, 4.44-cm internal diameter plexiglass tubes, with 5 cm of fiberglass as a false floor. Six storage containers were used, and each was loaded with 839 to 961 g of corn. Appendix B lists all initial column weights. An airflow rate of about 0.6 m^3/min*t (0.53 cfm/bu) was set, and controlled by a pressure regulator. The airflow rate was monitored using Matheson Model PM-1022 Acrylic Purge Flowmeters. The system was checked for air leaks at 12-h intervals.

Production of H_2O and CO_2 are results of grain and microorganism respiration. These two components are mixed in the air outgoing from the sample storage unit. In this experiment, two drying agents were used to absorb H_2O vapor. The first was a 1:1 mix of 8-mesh drierite (anhydrous $CaSO_4$) and 8-mesh indicating drierite (97% $CaSO_4$ and 3% $COCl_2$). To ensure complete absorption of H_2O vapor, the air stream was then passed through a second agent, magnesium perchlorate (Mg

$(ClO_4)_2)$, setup as in Al-Yahya (1991). The exiting air from section three passed through the CO_2 absorption section. Sulaimanite, a CO_2 absorption agent described by Al-Yahya (1991) was used, being placed in plexiglass tubes (2.54-cm inner diameter). Since absorption of CO_2 is accompanied by release of H_2O, 15 cm of drying agents (drierite and magnesium perchlorate) were used to absorb water liberated from the sulaimanite compound. CO_2 absorption tubes were weighed at 10 to 15-h intervals to determine the mass of CO_2 evolved.

STATISTICAL ANALYSIS

The SAS package was used for the study, which included five mold inhibitor treatments, three levels of mechanical kernel damage and two replications. A two-way analysis of variance (ANOVA) was used for the data collected. Orthogonal contrasts where used to make comparisons among treatment means (Snedecor and Cochran, 1989). Comparisons where made for combine versus hand-shelled, combine versus half and half, and half and half versus hand-shelled corn samples. Interactions between the different damage levels and fungicide treatments for times required for the dry matter loss (DML) to reach 0.5% were also considered.

RESULTS AND DISCUSSION

Dry Matter Loss

Raw data of the CO_2 evolution over time is given in Appendix A. Figures 1-3 are plots of least square equations of corn dry matter loss versus storage time. Each line represents pooled data from two replicates. Equations of the lines are given in Appendix D. Table 1 gives mean storage times to 0.5% DML for all five treatments, along with the percent of control values and least significant differences. From Table 1 note that fungicide treatments are more effective on corn having higher levels of mechanical damage.

Statistical analysis results in the form of estimate contrasts among the means are presented in Table 2.

From Table 2, note that

* The times for combine shelled corn (25.1% kernel damage) to reach 0.5% DML were significantly lower than those for the half and half samples.
* Times for both combine shelled and half and half samples were significantly lower than for the hand shelled corn.
* Times for iprodione-treated samples to reach 0.5% DML were significantly greater than for the control samples.
* Times for samples treated with surfactant were not

significantly greater than times for samples without surfactant at the 20 ppm iprodione level or the 15 ppm iprodione level.

* Times for samples treated with 15 ppm were significantly lower than samples treated with 20 ppm.
* There was a significant interaction between shelling method and treatment type for the 20 and 20^{+} ppm samples.
* No other contrast comparisons where significant.

The variability in Table 1 and Table 2 could be caused by differences in mechanical damage levels, types of kernel damage, moisture content variation, and initial fungal spore load among samples. Part of the variability might also be caused by slight differences in the actual level of fungicide applied. Therefore, even greater variability may be expected in on-farm tests.

Total Damaged Kernels

After samples reached the 0.5% DML level, they were removed from the storage tubes and spread out one kernel deep to dry in the laboratory.

Total damaged kernel (DKT) values of these samples are presented in Table 3. Values where determined by Central Iowa

Grain Inspection Service (CIGIS) graders. Samples were coded so that graders were not biased by knowledge of the treatment for each sample. Statistical analyses results in the form of estimate contrast among the means are listed in Table 4. From Table 4, note that

* DKT for combine-shelled corn (26% kernel damage) at 0.5% DML were not significantly different than that for the mixture of half-and half-corn.
* DKT for both combine shelled and half-and-half samples at 0.5% DML were significantly higher than for the hand-shelled corn.
* DKT for iprodione-treated samples were not significantly different than for the control samples at 0.5% DML.
* DKT for iprodione-treated samples were significantly greater than DKT for 15^+ ppm compared to 15 ppm but not for 20^+ ppm, compared to 20 ppm.
* There is a significant interaction between the harvest type and treatment type for the 20 and 20^+ ppm samples.
* No other contrast comparisons were significant.

DKT values determined by the CIGIS were greater for higher levels of mechanical damage. The CIGIS results where consistent with those reported by Saul and Steele (1966) who found that at 0.5% DML, mold damage is greater in samples that had greater mechanical damage. The data are also consistent with studies by Friday (1989), in which the percent mold damage varied from 8.6 to 16.2%.

DKT results for this study and those of Wilcke et al. (1992) both demonstrated high variability. They found some significant differences among damage levels and treatments, but they judged these results to be unreliable because of inconsistencies among graders.

CONCLUSIONS

This research studied the effectiveness of the fungicide iprodione on 22% moisture (wet basis) corn stored at 20°C. Corn having three initial levels of damage (7.1%, 16.2%, and 25.3%) was treated with 0, 15, 20 ppm iprodione, and 15 and 20 ppm iprodione plus 0.25% surfactant. The conclusions of the study are:

* Corn samples treated with iprodione fungicide required significantly longer times to loose 0.5% dry matter than those required for untreated corn. Storage times for samples treated with 15 ppm and 20 ppm were 114% and 129% of control sample times, respectively.

* Fungicide activator did not significantly extend the storage time to 0.5% DML for 20^{+} ppm treatment, or the 15^{+} ppm treatment.

* Corn samples with higher levels of kernel damage, required lower times to reach the 0.5% DML. Storage times for combine shelled samples had a 131% increase compared to hand shelled samples which had a 112% increase over control sample times.

REFERENCES

Aljinovic, S., 1993. Carbon dioxide evolution of high-moisture shelled corn treated with iprodione. Unpublished M.S. Thesis. Parks Library. Iowa State University, Ames, IA.

Al-Yahya, S.A., C.J. Bern, M.K. Misra and T.B. Bailey. 1993. Carbon-dioxide evolution of fungicide-treated high moisture corn. Transactions of the ASAE. 36(4):??-??.

Al-Yahya, S.A., 1991. Fungicide treatment of high-moisture corn. Unpublished Ph.D. Dissertation. Iowa State University, Ames, IA. No. 9202336.

Cantone, F.A., J. Tuite, L.F. Bauman and R. Stroshine. 1983. Genotypic differences in reaction of stored corn kernels to attack by selected <u>Aspergillus</u> and <u>Penicillium</u> <u>spp</u>. Phytopathology 73(9):1250-1255.

Chowdhury, M. H., W. F. Buchele. 1976. Development of a numerical damage index for critical evaluation of mechanical damage of corn. Transactions of the ASAE 19(2):428-432.

Fernandez, A., R. Stroshine and J. Tuite. 1985. Mold growth and carbon dioxide production during storage of high moisture corn. Cereal Chem. 62(2):137-144.

Friday, D.C., J. Tuite, and R. Stroshine. 1989. Effect of hybrid and physical damage on mold development and carbon dioxide production during storage of high moisture shelled corn. Cereal Chem. 66(5):422-426.

Ghate, S.R., W.K. Bilanski and J.B. Robinson. 1980. Urea and Chemstor as preservatives for high moisture corn. Transactions of the ASAE 23(6):1569-1572.

Moreno - Martinez, E., and C.M. Christensen. 1971. Differences among lines in varieties of maize in susceptibility to damage by storage fungi. Phytopathology 61(12):1498-1500.

Rhone-Poulenc Ag Company. 1990. Rovral 50WP/Rovral 4F fungicide. Rhone-Poulenc Ag Company, Research Triangle Park, NC.

Saul, R.A. and E.F. Lind. 1958. Maximum time for safe drying of grain with unheated air. Transactions of the ASAE 1(1):29-33.

Saul, R.A., and J.L. Steele. 1966. Why damaged shelled corn costs more to dry. Agricultural Engineering 47(6):326-329, 337.

Sauer, D.B., and R. Burroughs. 1974. Efficiency of various chemicals as grain mold inhibitors. Transactions of the ASAE. 17(3):557-559.

Snedecor, G.W., and W.G. Cochran. 1989. Statistical methods, 8th ed. Iowa State University Press, Ames, Iowa.

Stroshine, R.L., and X. Yang. 1990. Effects of Hybrid and grain damage on estimated dry matter loss for high moisture shelled corn. Transactions of the ASAE 33(4):1291-1298.

Thompson T.L. 1972. Temporary storage of high moisture shelled corn using continuous aeration. Transactions of the ASAE 15(2):333-337.

Tuite, J., C. Koh-Knox, R. Stroshine, F.A. Cantone and L.F. Bauman. 1985. Effect of physical damage to corn kernels on the development of Penicillium spp. and Aspergillus glaucus in storage. Phytopathology 75(10):1 137-1140.

Yasin, M., and M.A. Hanna. 1984. Potassium sorbate as a preservative for high moisture corn. ASAE Paper 84-3009. St. Joseph, MI: ASAE.

Wilke, W.F., R.A. Meronuck, R.V. Morey, H.F. Ng, J.P. Lang, D. Jiang. 1992. Deterioration rates of shelled corn treated with mold inhibitors. ASAE Paper No. 916557. St. Joseph, MI: ASAE.

White, D.G., Shove, G.C., and W.H. Peterson. 1988. Fungicides reduce corn drying and storage risks. ASAE Paper 88-6075. St. Joseph, MI:ASAE.

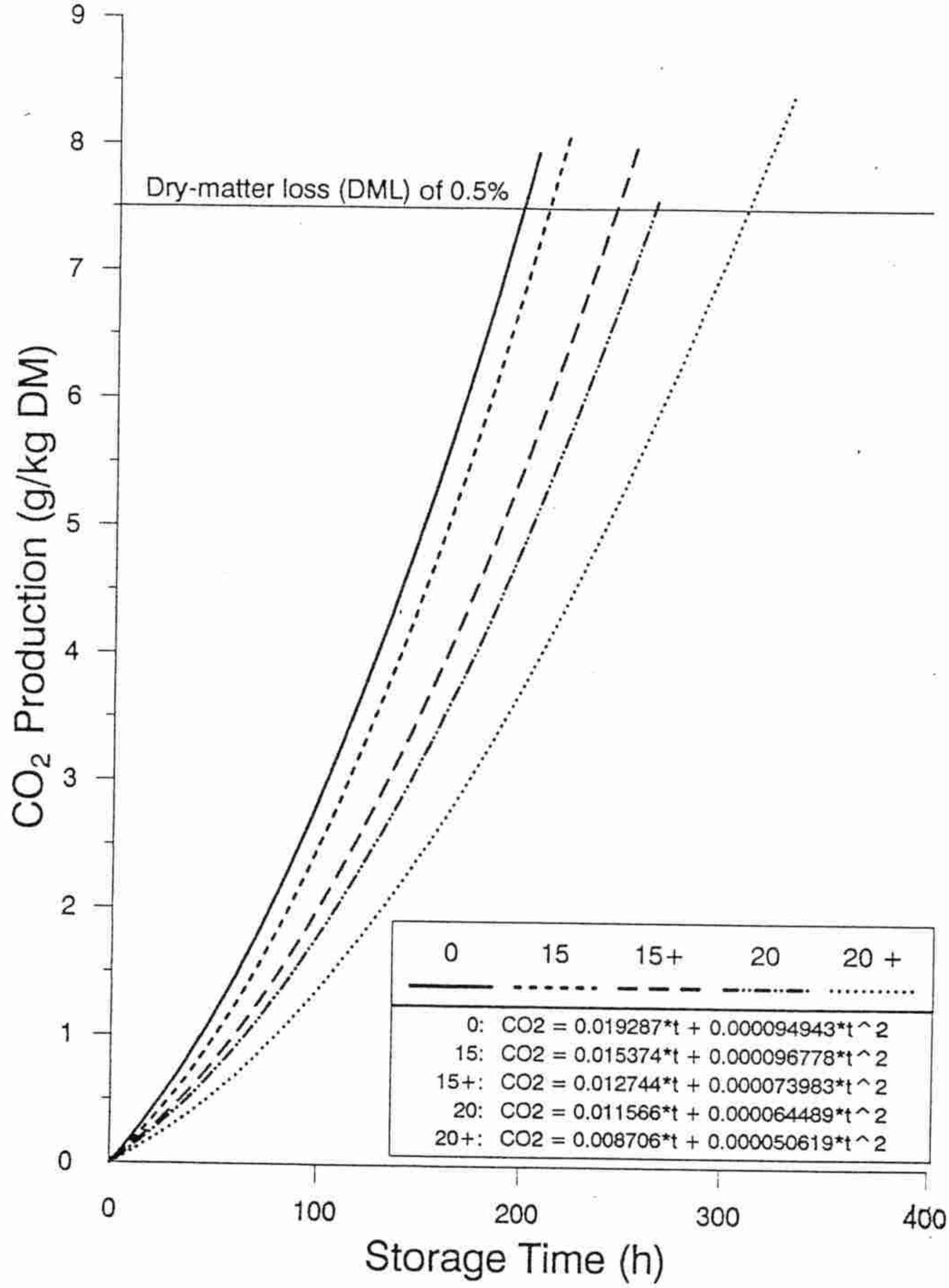

Figure 1. Carbon dioxide production by combine shelled corn treated with different rates of iprodione.

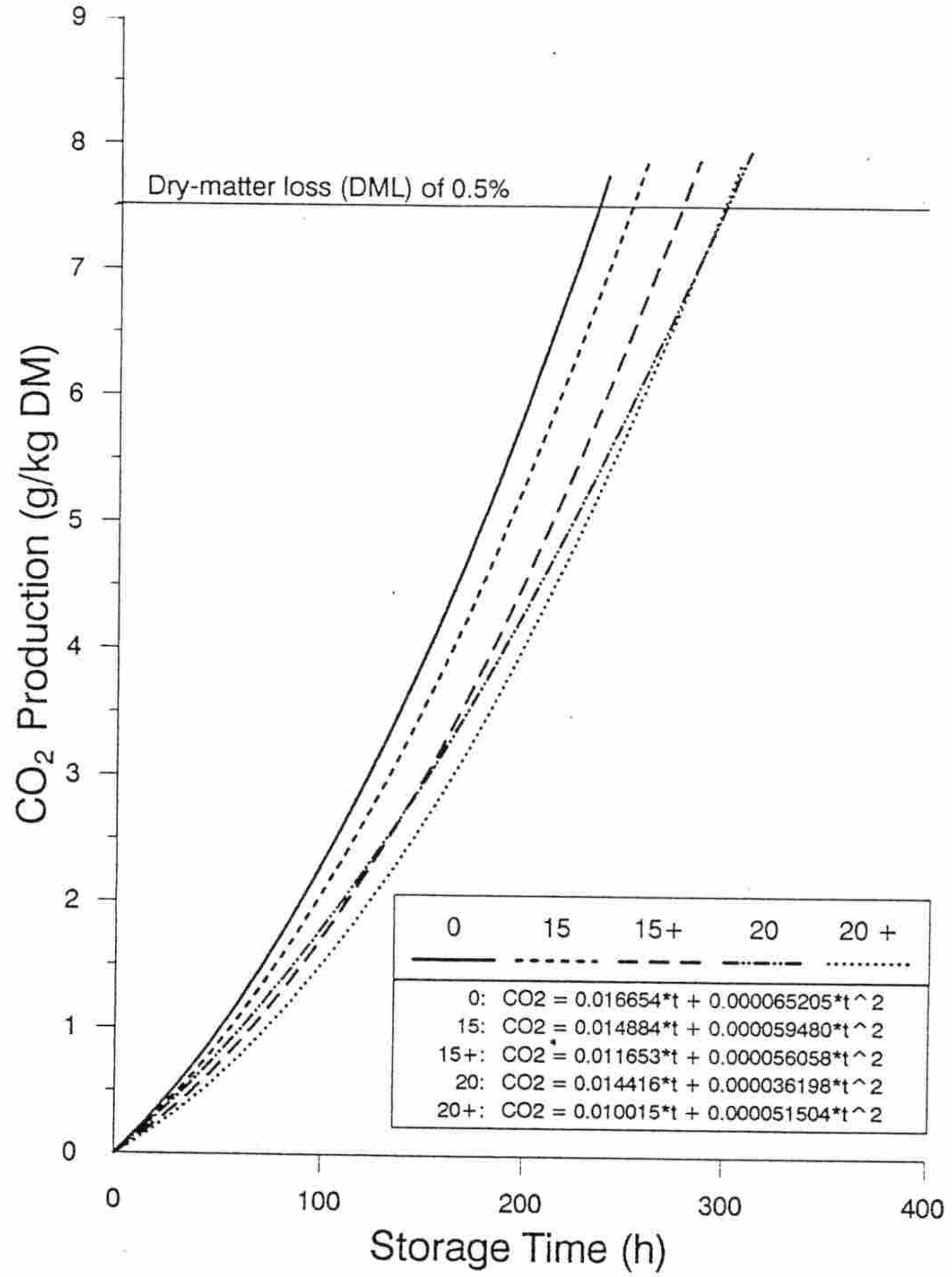

Figure 2. Carbon dioxide production by a mixture of half hand and half combine shelled corn treated with different rates of iprodione.

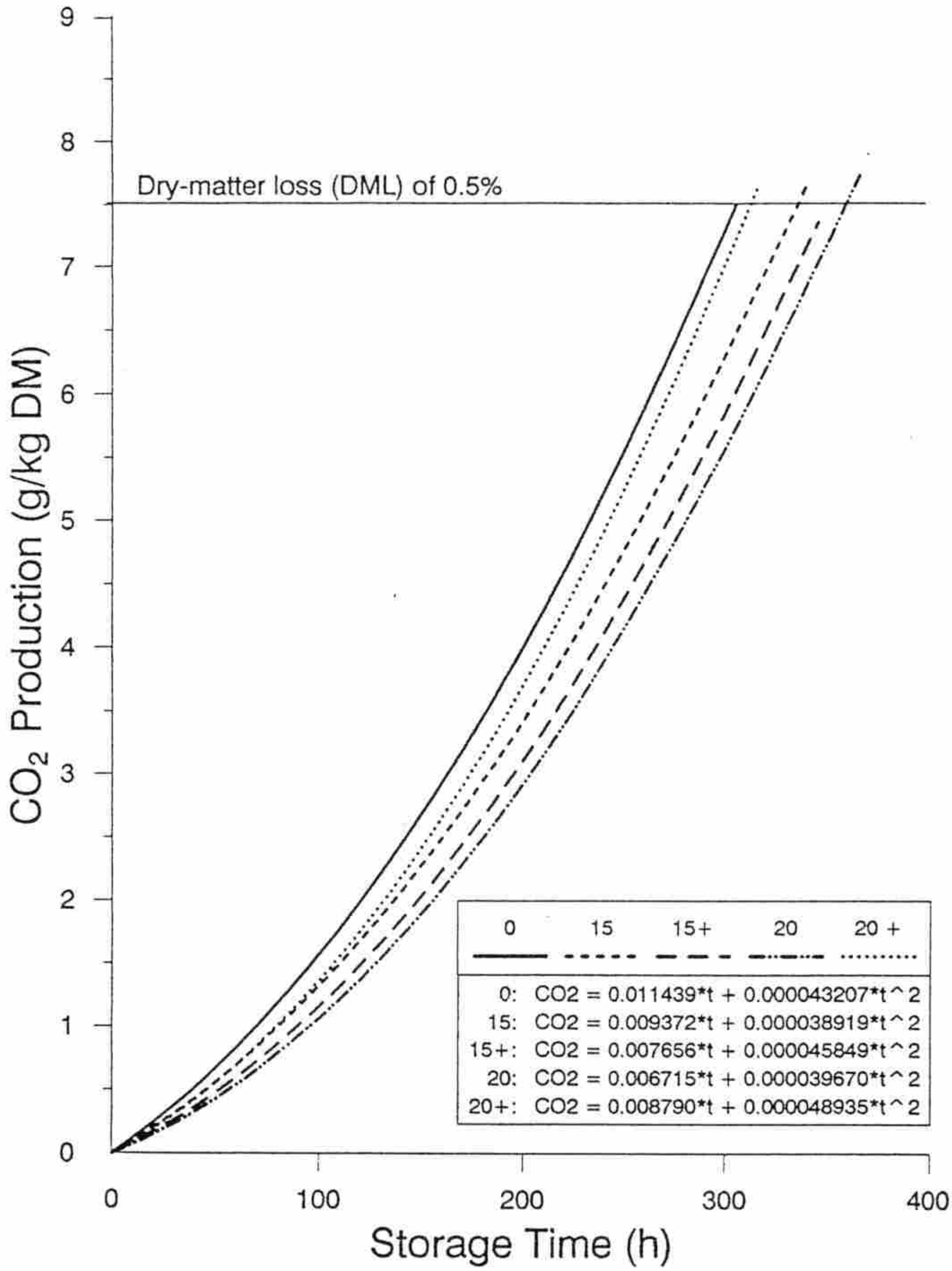

Figure 3. Carbon dioxide production by hand shelled corn treated with different rates of iprodione.

Table 1. Storage life (time to 0.5% dry matter loss) for corn samples treated with iprodione.

Mechanical damage	Treatments (ppm)				
	0*	15	15+	20	20+
	Storage life, h				
25% damage (combine shelled)					
Rep 1	193	212	247	264	321
Rep 2	199	206	242	261	294
Avg	196	209	245	263	308
% of control	100	107	126	134	157
16% damage (half and half)					
Rep 1	230	258	284	293	302
Rep 2	238	244	268	309	288
Avg	234	251	276	301	295
% of control	100	107	118	129	126
7% damage (hand shelled)					
Rep 1	292	335	335	356	308
Rep 2	303	337	326	361	309
Avg	297	336	330	359	309
% of control	100	113	111	121	104

* Control
\+ Activator 90 surfactant added

Table 2. Estimated values (storage times (h) to 0.5% DML) of comparisons among treatment means.

Contrast	Result	Estimate (Std. Dev.)
C1: Combine - Half	sig.	-46.2 (15.8)
C2: Combine - Hand	sig.	-97.0 (15.76)
C3: Half - Hand	sig.	-50.8 (15.76)
C4: Control - All	sig.	45.79(16.1)
C5: 15 - 15+	not sig.	6.0 (20.3)
C6: 20- 20+	sig.	-147.67(20.3)
C7: C1 * C4	not sig.	21.63(39.4)
C8: C1 * C5	not sig.	68.0 (49.8)
C9: C1 * C6	not sig.	-67.0 (49.8)
C10: C2 * C4	not sig.	46.88(39.39)
C11: C2 * C5	not sig.	22.0 (49.83)
C12: C2 * C6	sig.	-148.5 (49.83)
C13: C3 * C4	not sig.	-27.0 (70.74)
C14: C3 * C5	not sig.	-46.0 (49.83)
C15: C3 * C5	not sig.	-81.5 (49.83)

+ Activator 90 surfactant added

Table 3. Total damaged kernels (DKT) at 0.5% corn dry matter loss for iprodione treated corn samples.

Mechanical damage	Treatments (ppm)				
	0*	15	15+	20	20+
	DKT, %				
25% damage (combine shelled)					
Rep 1	12.1	18.6	15.8	14.7	9.4
Rep 2	10.9	29.4	13.6	20.0	6.3
Avg	11.5	24.0	14.7	17.4	12.9
16% damage (half and half)					
Rep 1	7.8	10.6	3.3	13.9	30.7
Rep 2	8.8	14.3	2.9	14.8	17.5
Avg	8.3	12.5	3.1	14.4	24.1
7% damage (hand shelled)					
Rep 1	14.1	13.2	10.4	3.4	5.0
Rep 2	3.8	13.4	12.2	1.3	5.6
Avg	9.0	13.3	11.3	2.3	5.3

* Control

\+ Activator 90 surfactant added.

Table 4. Estimated values (of DKT for 0.5% DML) of comparisons among treatment means in the fungicide experiment.

Contrast	Result	Estimate (Std. Dev.)
C1: Combine - Half	not sig.	3.62(1.82)
C2: Combine - Hand	sig.	7.84(1.82)
C3: Half - Hand	sig.	4.22(1.82)
C4: Control - All	not sig.	3.35(1.85)
C5: 15 - 15+	sig.	6.88(2.35)
C6: 20 - 20+	not sig.	-2.72(2.35)
C7: C1 * C4	not sig.	0.53(4.54)
C8: C1 * C5	not sig.	-0.05(5.75)
C9: C1 * C6	sig.	14.25(5.75)
C10: C2 * C4	not sig.	6.61(4.51)
C11: C2 * C5	not sig.	7.3 (5.75)
C12: C2 * C6	not sig.	7.45(5.75)
C13: C3 * C4	not sig.	6.09(4.54)
C14: C3 * C5	not sig.	7.35(5.75)
C15: C3 * C6	not sig.	-6.8 (5.75)

+ Activator 90 surfactant added

GENERAL CONCLUSION

Todays agriculture is faced with two burning issues. It strives to increase food production, while minimizing environmental damage. This study is a step towards achieving these to steps since it has focused on:

* Finding ways to decrease large corn storage losses.
* Finding the optimal rates of application for fungicides applied to a stored grain mass, reducing potential adverse environmental effects.

This study also indicates that further research needs to focus on:

* Development of tehniques to asses DKT and research on effects of various types of DKT on the corn grain deterioration rate.
* Development of biological control methods of corn deterioration rates.
* Understanding the genetical mechanisms and breeding of fungi resistant corn hybrids.

LITERATURE CITED

Anonymous. 1991. Statistical profile of Iowa. Iowa Department of Economic Development, Des Moines, IA.

FAO, 1992. Production Yearbook. Vol. 45, FAO, Rome.

FAO, 1985. Prevention of post-harvest food losses. FAO Training Series, No. 10., FAO, Rome.

Simpkins William. 1993. Personal communications. Iowa State University.

Ware, G.W. 1987. The pesticide book. Thompson Publications, Fresno, CA.

ACKNOWLEDGEMENTS

I would like to thank Dr. Bern for his guidance and support during my MS study program, which greatly helped me succesfully complete my studies.

I would also like to thank all the professors at Iowa State University, which passed on to me their knowledge in various study fields.

Last of all, I would like to thank all the personel at Iowa State University, that helped me sucessfully complete this degree.

Appendix A. Carbon dioxide evolution raw data

Table A-1. Raw data of carbon-dioxide production weight gain in grams for combine shelled, half and half and hand shelled corn for the 0 ppm (control) treatment level.

Time, h	Combine shelled R1	Combine shelled R2	Half and half R1	Half and half R2	Hand shelled R1	Hand shelled R2
0	0	0	0	0	0	0
14	0.21	0.20	0.15	0.15	0.09	0.08
25.75	0.20	0.17	0.19	0.20	0.14	0.13
42.5	0.23	0.23	0.21	0.19	0.15	0.13
56.5	0.28	0.25	0.19	0.20	0.14	0.13
66.5	0.25	0.24	0.20	0.21	0.16	0.15
78.5	0.27	0.27	0.22	0.23	0.17	0.14
87.5	0.25	0.27	0.17	0.22	0.15	0.13
100.5	0.28	0.30	0.25	0.24	0.17	0.17
111.5	0.27	0.29	0.23	0.24	0.15	0.14
123.5	0.31	0.30	0.27	0.26	0.18	0.20
134.5	0.36	0.32	0.25	0.28	0.19	0.17
147.5	0.36	0.40	0.28	0.27	0.21	0.19
159.5	0.40	0.41	0.31	0.28	0.22	0.20
171.5	0.43	0.43	0.33	0.29	0.20	0.19
183.5	0.44	0.44	0.38	0.34	0.21	0.20
195.5	0.46	0.46	0.37	0.35	0.19	0.22
208.5	----	0.48	0.40	0.35	0.21	0.25
220.5	----	----	0.39	0.36	0.25	0.23
232.5	----	----	0.44	0.37	0.26	0.24
244.5	----	----	----	0.39	0.25	0.23
246.5	----	----	----	----	0.03	0.04
258.5	----	----	----	----	0.29	0.26
266	----	----	----	----	0.23	0.21
276	----	----	----	----	0.31	0.28
282	----	----	----	----	0.18	0.19
294	----	----	----	----	0.38	0.39
306	----	----	----	----	----	0.43

Table A-2. Raw data of carbon-dioxide production weight gain in grams for combine shelled, half and half and hand shelled corn for the 15 ppm treatment level.

	Combine shelled		Half and half		Hand shelled	
Time, h	R1	R2	R1	R2	R1	R2
0	0	0	0	0	0	0
12	0.12	0.11	0.11	0.10	0.10	0.10
24	0.17	0.17	0.14	0.16	0.12	0.11
36	0.18	0.19	0.18	0.20	0.16	0.15
48	0.19	0.19	0.13	0.14	0.08	0.07
60	0.23	0.25	0.23	0.24	0.19	0.17
62	0.02	0.02	0.02	0.03	0.01	0.02
74	0.23	0.26	0.16	0.15	0.10	0.12
86	0.22	0.21	0.14	0.17	0.08	0.09
98	0.24	0.28	0.20	0.22	0.15	0.15
110	0.27	0.24	0.14	0.16	0.09	0.08
122	0.32	0.32	0.22	0.26	0.11	0.11
134	0.31	0.29	0.24	0.26	0.13	0.13
146	0.32	0.33	0.23	0.25	0.12	0.14
158	0.32	0.38	0.25	0.27	0.15	0.14
170	0.35	0.41	0.27	0.27	0.17	0.16
171	0.04	0.05	0.04	0.05	0.04	0.03
182	0.36	0.43	0.28	0.28	0.18	0.19
194	0.38	0.45	0.29	0.30	0.20	0.21
206	0.44	0.48	0.32	0.34	0.23	0.24
218	0.46	0.51	0.30	0.35	0.24	0.24
230	----	----	0.32	0.38	0.25	0.24
242	----	----	0.33	0.36	0.25	0.26
254	----	----	0.29	0.38	0.22	0.23
263	----	----	0.2	----	0.22	0.24
275	----	----	----	----	0.24	0.23
278	----	----	----	----	0.09	0.08
290	----	----	----	----	0.22	0.23
302	----	----	----	----	0.23	0.22
314	----	----	----	----	0.30	0.26
326	----	----	----	----	0.24	0.23
339.5	----	----	----	----	0.35	0.33

Table A-3. Raw data of carbon-dioxide production weight gain in grams for combine shelled, half and half and hand shelled corn for the 15+ ppm treatment level.

	Combine shelled		Half and half		Hand shelled	
Time, h	R1	R2	R1	R2	R1	R2
0	0	0	0	0	0	0
6	0.07	0.09	0.06	0.09	0.04	0.05
31	0.16	0.24	0.10	0.14	0.05	0.06
43	0.17	0.22	0.12	0.16	0.09	0.11
55	0.18	0.20	0.15	0.18	0.12	0.10
67	0.20	0.21	0.16	0.19	0.12	0.12
79	0.22	0.22	0.17	0.18	0.15	0.14
91	0.22	0.24	0.18	0.19	0.14	0.16
103	0.24	0.23	0.16	0.19	0.16	0.15
115	0.23	0.24	0.19	0.20	0.19	0.18
127	0.23	0.26	0.20	0.21	0.21	0.18
139	0.25	0.28	0.25	0.26	0.19	0.22
151	0.32	0.32	0.23	0.24	0.19	0.20
163	0.31	0.37	0.25	0.26	0.21	0.22
175	0.32	0.35	0.26	0.25	0.20	0.21
199	0.74	0.76	0.54	0.57	0.44	0.42
223	0.72	0.75	0.58	0.61	0.48	0.41
247	0.77	0.80	0.57	0.63	0.50	0.46
271	----	----	0.63	0.67	0.56	0.53
295	----	----	0.66	----	0.58	0.57
319	----	----	----	----	0.62	0.61
343	----	----	----	----	0.67	0.64

Table A-4. Raw data of carbon-dioxide production weight gain in grams for combine shelled, half and half and hand shelled corn for the 20 ppm treatment level.

	Combine shelled		Half and half		Hand shelled	
Time, h	R1	R2	R1	R2	R1	R2
0	0	0	0	0	0	0
12	0.14	0.16	0.11	0.1	0.06	0.05
14.83	0.02	0.05	0.02	0.01	0.01	0.02
21.33	0.05	0.06	0.03	0.03	0.03	0.02
26.99	0.03	0.05	0.06	0.06	0.08	0.03
35.83	0.07	0.09	0.07	0.05	0.04	0.05
47.83	0.18	0.16	0.18	0.18	0.13	0.14
53.83	0.06	0.06	0.09	0.09	0.05	0.06
59.83	0.04	0.02	0.05	0.04	0.03	0.03
71.83	0.18	0.15	0.18	0.16	0.11	0.12
77.83	0.13	0.11	0.11	0.11	0.04	0.04
83.83	0.11	0.10	0.09	0.09	0.05	0.03
84.83	0.03	0.03	0.02	0.02	0.02	0.01
96.83	0.22	0.25	0.19	0.22	0.14	0.11
108.83	0.21	0.23	0.19	0.18	0.13	0.10
132.83	0.48	0.48	0.41	0.44	0.22	0.25
144.83	0.27	0.23	0.26	0.24	0.15	0.18
156.83	0.22	0.22	0.25	0.23	0.17	0.18
168.83	0.27	0.27	0.27	0.25	0.2	0.19
180.83	0.29	0.31	0.21	0.22	0.19	0.17
192.83	0.32	0.33	0.26	0.26	0.24	0.20
205.83	0.32	0.34	0.27	0.24	0.23	0.21
218.83	0.34	0.35	0.28	0.27	0.24	0.18
229.83	0.35	0.37	0.22	0.23	0.21	0.16
241.83	0.36	0.4	0.25	0.25	0.23	0.21
253.83	0.37	0.39	0.29	0.26	0.24	0.23
265.83	0.39	0.4	0.31	0.28	0.22	0.27
277.83	----	----	0.30	0.18	0.21	0.26
294.08	----	----	0.34	0.29	0.29	0.31
306.08	----	----	----	0.30	0.27	0.29
319.08	----	----	----	0.28	0.26	0.28
325.08	----	----	----	----	0.17	0.17
350.08	----	----	----	----	0.57	0.63
362.08	----	----	----	----	0.31	0.31

Table A-5. Raw data of carbon-dioxide production weight gain in grams for combine shelled, half and half and hand shelled corn for the 20^{+} ppm treatment level.

Time, h	Combine shelled R1	Combine shelled R2	Half and half R1	Half and half R2	Hand shelled R1	Hand shelled R2
0	0	0	0	0	0	0
24	0.15	0.14	0.18	0.15	0.24	0.22
48	----	----	0.26	0.23	0.19	0.04
50.5	0.17	0.21	----	----	----	----
72	0.2	0.23	----	----	----	----
74.5	----	----	0.29	0.28	0.31	0.28
96	----	----	0.33	0.3	0.26	0.17
99	0.3	0.31	----	----	----	----
123	----	----	0.32	0.39	0.37	0.66
123.5	0.32	0.41	----	----	----	----
147	0.36	0.43	----	----	----	----
147.5	----	----	0.44	0.44	0.39	0.34
170	----	----	0.42	0.48	0.35	0.34
170.5	0.37	0.59	----	----	----	----
193.5	----	----	0.41	0.45	0.41	0.36
195	0.53	0.64	----	----	----	----
214	0.34	0.41	----	----	----	----
218	----	----	0.69	0.50	0.49	0.46
237	----	----	0.45	0.39	0.39	0.31
238	0.48	0.63	----	----	----	----
262	----	----	0.64	0.62	0.61	0.49
265	0.56	0.70	----	----	----	----
289	0.54	0.68	0.79	0.71	0.80	0.67
313	----	----	0.75	----	0.87	0.74
313.5	0.63	0.70	----	----	----	----
337.5	0.63	----	----	----	----	----

Appendix B. Sample weights.

Table B-1. Initial corn sample weights (g).

Weight (g)	Treatments (ppm)				
	0*	15	15+	20	20+
25% damage (combine shelled)					
Rep 1	839.53	844.5	912.6	920	880.15
Rep 2	875.6	867.7	961.1	931.1	875.6
18% damage (half and half)					
Rep 1	864.4	839.4	883.5	902.9	960.1
Rep 2	889.4	856.2	877.2	912.8	840.6
7% damage (hand shelld)					
Rep 1	862.9	880.6	973.1	921.6	942.1
Rep 2	890.78	878.5	904.8	934.6	844.9

* Control
+ Activator 90 surfactant added

Appendix C. Final moisture content of samples.

Table C-1. Final moisture content (% wet basis) for corn samples treated with iprodione.

Mechanical damage	Treatments (ppm)				
	0*	15	15+	20	20+
	Moisture content, %				
25% damage					
Rep 1	21.6	23.7	22.3	20.3	23.0
	22.7	23.7	22.9	19.7	25.2
Rep 2	22.7	24.1	22.3	20.7	23.1
	22.5	24.2	21.9	20.7	23.2
Avg	22.4	23.9	22.3	20.4	23.6
18% damage					
Rep 1	22.6	22.7	23.2	20.6	24.0
	22.5	23.1	23.4	20.5	24.1
Rep 2	23.4	23.1	23.0	22.3	23.7
	23.4	23.9	23.5	21.6	23.9
Avg	23.0	23.2	23.3	21.3	23.9
7% damage					
Rep 1	22.4	22.8	22.7	21.5	24.1
	22.5	23.2	22.4	21.3	24.0
Rep 2	22.3	23.0	22.6	22.5	23.6
	22.9	22.3	23.0	22.7	23.5
Avg	22.5	22.8	22.7	22.0	23.8

* Control
+ Activator 90 surfactant added

Appendix D. Equations of CO_2 production.

Table D-1. Equations of CO_2 production of combine harvested samples treated with different rates of iprodione.

Treatment	Equation (t=time, h)
0* ppm	$0.019287*t + 0.000094943*t^2$
15 ppm	$0.015374*t + 0.000096778*t^2$
15+ ppm	$0.012744*t + 0.000073983*t^2$
20 ppm	$0.011566*t + 0.000064489*t^2$
20+ ppm	$0.008706*t + 0.000050619*t^2$

* Control
+ Activator 90 surfactant added.

Table D-2. Equations of CO_2 production for hand harvested samples treated with different rates of iprodione.

Treatment	Equation (t=time, h)
0^* ppm	$0.011439*t + 0.000043207*t^2$
15 ppm	$0.009372*t + 0.000038919*t^2$
15^+ ppm	$0.007656*t + 0.000045849*t^2$
20 ppm	$0.006715*t + 0.000039670*t^2$
20^+ ppm	$0.008790*t + 0.000048935*t^2$

* Control
\+ Activator 90 surfactant added.

Table D-3. Equations of CO_2 production for half and half samples treated with different rates of iprodione.

Treatment	Equation (t=time, h)
0^* ppm	$0.016654*t + 0.000065205*t^2$
15 ppm	$0.014884*t + 0.000059480*t^2$
15^+ ppm	$0.011653*t + 0.000056058*t^2$
20 ppm	$0.014416*t + 0.000036198*t^2$
20^+ ppm	$0.010015*t + 0.000051504*t^2$

* Control
+ Activator 90 surfactant added.